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Control of Pollution From Outboard Engine Exhaust: A Reconnaissance Study

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Tests made in a swimming tank with an untuned engine have shown that the quantity of fuel wasted as exhaust varied from about 7 percent of the volume of fuel used at high speeds, to over 30 percent at low speeds. For a recently tuned engine, the quantity of fuel discharged ranged from about 3 percent at high speeds to about 26 percent at low speeds. When the Goggi pollution control device was installed, these quantities were intercepted and collected rather than discharged with the exhaust.

Analysis at various depths indicated that nearly all products separated from the water in a short time and collected on the surface. Very little dissolved or emulsified oil was noted. Various analytical techniques were studied.

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CONTROL OF POLLUTION FROM OUTBOARD ENGINE EXHAUST:

A RECONNAISSANCE STUDY

by

Bio-Environmental Engineering Division
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for the

ENVIRONMENTAL PROTECTION AGENCY

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SECTION I - CONCLUSIONS

Major efforts in this study have been directed towards defining the nature and extent of the pollution problems as they originate with outboard engines. Of necessity, the scope of this work has been limited because of the short time available for this work. However, data obtained by the operation of the two-cycle outboard engines in test tanks under a variety of conditions have provided definitive information regarding the amount and kinds of exhaust products discharged to surroundings.

Tests were made with both an untuned and a tuned two-cycle outboard engine at various engine speeds. These tests were made with a Goggi pollution control device attached to the engine. This device provides for the collection of liquid fuel and exhaust products rather than their discharge to the water. The results of these tests have shown that from untuned engines to which a Goggi device is attached, the volume of exhaust products collected ranged from about 7 percent of the volume of fuel used at high speeds to over 30 percent at low speeds. The amount of fuel and exhaust products collected from a recently tuned engine ranged from about 3 percent at high speeds to about 26 percent at low speeds. Without the Goggi device attached to the engine, these quantities of fuel and exhaust products would normally be discharged to the water.

Based upon test results from these studies, a calculation was made to illustrate the effect that exhaust products have on the aquatic environment. If one takes a discharge of 400 ml of exhaust products per 30 minutes operation as typical of average operation, this may be transformed into a waste load in terms of a population equivalent. Assuming that the products contain 85 percent biodegradable carbon, the discharge based on one engine-day would be equivalent to a population of 400 people.

For engines operated without an anti-pollution device, the exhaust products were discharged directly to the water beneath the surface. Observations of the water in the tank have shown that the exhaust products rapidly separated and accumulated in pools on the surface. Very little exhaust material was found to be retained in the water below the top few inches. This was verified by several analytical techniques, including organic carbon determinations, use of the oil test papers, and the use of the Esso oil analyzer.

A variety of analytical procedures for oil determination were investigated. A limited amount of work was done with a gas chromatograph. It soon became apparent that while potentially capable of yielding extremely useful data, the amount of preliminary testing and calibration required made it impractical to use this device extensively in a reconnaissance study. It was found that the Beckman carbon analyzer provided useful information regarding the presence of exhaust products. Analysis of samples taken at various depths showed that the total carbon content increased with time of engine operation. At the same time organic carbon content remained virtually constant both with respect to time and position except for the very top surface. It is believed that the increase in total carbon was due primarily to dissolved CO_2.

It was originally planned to investigate the amount of oil adsorbed on suspended solids, such as muds. However, because of the very low concentrations of oil found in the regions beneath the surface, and because of the time required to clean and fill the tanks between runs with muds present, it was felt that the limited time available could better be used in studying other aspects of the problem, and deferring this work to future studies.

Biodegradability studies of engine fuel (50:1), as well as exhaust products from operation of an engine at various speeds indicate that these materials are capable of supporting microbial growth. Comparative tests with ard without supplemental nitrogen show the same growth rates. Growth rates with fresh fuel were less than with engine exhaust products, perhaps due to higher concentrations of low volatile gasoline components. The studies indicate that growth rate is limited by available oxygen. Tests at various shaker speeds indicated a linear increase in cell numbers with shaker speed, which in turn is proportional to oxygen transfer capacity.

SECTION II - RECOMMENDATIONS

The present reconnaissance study has provided preliminary data on the quantity and distribution of exhaust products from outboard engines, plus information on the rates of biological degradation. This work has suggested a number of areas where further work should be done.

1. Further evaluation of analytical methods should be made for both quantitative and qualitative purposes. Efforts should be made to extend the method using the Esso analyzer. This method has the potential of being a rapid and convenient way of measuring the quantity of oil in water samples, but requires refinements in technique. The gas chromatograph can provide useful information on the identification of specific products discharged to the environment. Other methods need to be evaluated.

2. The tests to determine the amount of exhaust products, with and without the pollution control device, need to be extended over a wider range of operating conditions.

3. The effects of muds and suspended solids on the removal of exhaust products should be further investigated beyond work being done currently.

4. Further work on biodegradability is indicated over a wider range of environmental conditions. The preliminary work has indicated that oxygen transfer rates may be critical to degradation, and this needs to be studied.

5. Most importantly, this study should be extended to the field, in order to judge acceptable limits of discharge. These limits should be based on (a) the ability of the body of water with its accompanying flora to purify the pollutants; (b) the physical and chemical processes involved in removing the pollutants from their area of influence; and (c) a discharge that is unobjectionable in terms of water usage and ecological balance.

6. The effect of engine discharges on primary production should be studied by evaluation of periphytic and planktonic algae.

7. Studies should be made of the effects of operation of motors on the water quality, particularly with reference to those factors which are important in microbial growth. This includes all forms of nitrogen, phosphorus, dissolved oxygen; pH, calcium, sodium and chloride.

8. Studies should include comparisons between natural waters in which control devices are used and those where they are not.

SECTION III - INTRODUCTION

GENERAL

Increased usage of two-cycle outboard engines has directed attention to the possibility that exhaust from these engines may be coming to be a significant source of pollution to our lakes and rivers. An indication of the magnitude of the problem may be gained by noting the rate at which both the number of engines and their size is increasing. In 1959 there were 5.8 million outboard motors in use in the United States, having an average horsepower of 23.7. In 1969 there were 7.1 million outboard motors in use, and the average horsepower was 33.1.

Present fuel wastage from outboard motors has been variously reported at from 100 million gallons(17) to 160 million gallons(10) annually. A conservative estimate of the portion of fuel used which is discharged to the environment would be of the order of 10 percent of all outboard fuel used. The cost of the wastage probably lies between 50 million dollars and 100 million dollars just in out-of-pocket expense to boat owners.

While the effects of major oil pollution are obvious from such sources as ship spills, industrial transfer and storage, pipelines, and off-shore drilling(20,28), the effects of continuous low-level water pollution by outboard motors tends to be overlooked. However, there is increasing evidence that motor exhaust contributes to taste and odor in fish flesh(15,23,32,24,9), and that adverse biological effects are the result of this type of pollution.(27) The apparent persistence of oily wastes in water is also relevant to the frequent discharge of the exhaust streams from outboard motors.(14)

SOURCE OF OIL POLLUTION IN OUTBOARD MOTORS

At the present time, over 98 percent of all outboard motors used are two-cycle models. In this design a mixture of gasoline and oil is used as both fuel and as a lubricant for engine parts. The oil-gasoline-air mixture is valved directly from the carburetor to the crankcase which serves as the intake manifold. The downward thrust of the power stroke places the vaporized mixture under pressure. Due to this pressure the vapor is forced up into the firing portion of the cylinder and this pushes out the spent gases from the ignition stroke. During this process a portion of the vapor condenses within the crankcase on the internal parts of the engine. Most of the gasoline revaporizes since it is the more volatile and this leaves a thin film of oil behind to coat the engine parts. This process is repeated continuously while the engine is running.

Since the condensate does not reach the combustion chamber, it is not burned and thus begins to collect in the lower portion of the crankcase. If this liquid were allowed to accumulate in the crankcase, it would eventually build up to a point where the piston would be prevented from moving downward during its power stroke. This condition is known as "hydraulic lock" and may cause engine damage. To avoid this condition the liquid is evacuated from the crankcase by means of pressure-actuated valves. These valves are usually of the leaf or reed type.(28) When the liquid reaches a specified volume the downward stroke of the piston forces the valve open

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by the pressure exerted and the liquid fuel is vented. From there the waste fuel is led to the exhaust housing and downward to the water.

Therefore, the two-cycle engine is, by reason of its design, conducive to the rejection of varying amounts of unused, unburned fuel. The amount of this discharge will depend on the age and condition of the engine and on the speed of the operation. Fuel wastage has been estimated to range from less than 10 percent to over 50 percent of the fuel originally entering the engine.(28)

SCOPE AND PURPOSE

As a preliminary to comprehensive studies of the impact of outboard motors on a lake environment, a reconnaissance study has been made for the purpose of gaining an insight into the nature and magnitude of the pollution problem. The purpose of the present work has been to measure the quantity of exhaust products discharged from motors run in test tanks, as a function of operating time, water depth, and engine speed. Tests have been made both with and without a pollution control device attached to the engines. The control device allowed for collection of exhaust products instead of discharging to the water. Techniques for sampling and analyzing exhaust products have been evaluated, and information gathered on the distribution of discharged materials in the water environment. An additional objective of this work has been to study the biodegradability of outboard engine fuel and the exhaust products from outboard engines operated in various modes. This work has been carried on in laboratory shake flasks under a variety of environmental conditions.

SECTION IV - REVIEW OF RELATED WORK

Significant studies in the area of pollution from outboard motors have only recently become available. Perhaps the earliest of these was made by English, Henderson, McDermett, and Ettinger in 1961.(6,7) In this study two different outboard motors were tested in different volumes of water. The motors were 5.4 and 10 horsepower models operated in 50 and 380 gallons of water, respectively. It was found that the amount of extractable hydrocarbons and oxidizable material in the water after operation increased in direct proportion to the amount of time the motor was operated (at a constant speed). In addition, this relation seemed to hold even when the motors were operated in these small volumes until high contaminant concentrations were reached. An oil to fuel ratio of 1 to 17 was used for the study.

The study also studied the effects of the exhaust on the quality of the receiving water. This included measuring hydrocarbons, lead, effect on odor, chlorine demand, interference with coagulation, fish toxicity, and tainting of the fish flesh. Following a series of assumptions, an "extreme situation" was formulated. Using this extreme situation, concentrations of non-volatile and volatile oil, lead, phenols, and COD were calculated based on the concentrations found in the water after running the motors. From this it was concluded that "unusually low" water volume per unit of fuel consumed was needed before severe pollution would result from outboard motors alone. Apparently, the most noticeable effects were unpleasant taste and odor and the tainting of fish flesh.

Following the preliminary study, English, Surber, and McDermett carried out studies to determine what effect a natural environment would have on the waste products from outboard motors.(8) Three bodies of water were used - a motor lake, a motor pond, and a control pond. Tainting of fish flesh was found to occur at a combined fuel-use level of 8 gallons per million gallons of water and a daily fuel-use rate of 0.17 gallons per million gallons of water. It was also found that an increase in threshold odor number of between 0.5 and 1.5 occurred for each gallon of fuel consumed per million gallons of water. It was pointed out that temperature has an important effect on natural purification processes and that this should be taken into account when applying these figures to other areas of the world.

As with other types of pollution, the rate at which contaminants are added and the rate at which they are removed by natural processes determines the level of accumulation of the contaminants. In this study it was found that a higher fuel-use level was possible before fish flesh tainting occurred as compared to laboratory studies. This difference was attributed to the fact that less time was allowed for biological degradation of pollutants during the laboratory studies.

One other important conclusion of these field studies was that the amount of lead contributed by outboard motor exhausts was "insignificant".

In 1964, Dietrick investigated the polluting effects of underwater exhausts from outboard motors and the composition of the exhaust gases.(4)

He outlined the studies of English, McDermett, and Henderson and calculated the quantities of damaging substances discharged into Lake Constance per summer. His calculations were with reference to the possible effects on use of the lake as a source of drinking water supply. (This seems to be a recurring theme in most studies of this area.)

A significant advancement in outboard motor pollution abatement was made by the Goggi Corporation(10) in 1964. Using a patented device known as the Kleen Zaust, normally wasted fuel could be redirected into the fuel system. In this manner the discharge of unburned fuel into the water was completely eliminated. The device was connected to the motor in place of the crankcase bleeder valves and blocked off the segment of the valve which allowed the unburned fuel to go into the water. The crankcase pressure was utilized to redirect the flow to a mixing chamber and immediately redirected to the motor along with the fresh fuel drawn from the original mixture.

Tests run by an independent testing firm(25) were made on the Goggi device. A 33 horsepower Johnson Motor was used with a fuel mixture of 1 pint of oil per 6 gallons of gasoline. It was found that at engine idling speeds of 650 ± 100 RPM the device returned over 30 percent of the fuel drawn by the engine. With the engine in gear and using a test propeller, tests were run at 1000, 2000, and 3000 RPM. With the Goggi device connected, running time was increased by 68.8 percent, 66.7 percent, and 41.7 percent, respectively.

Extensive studies on pollution by outboard motors have also been conducted in Europe as evidenced by the report of Kempf, Ludemann, and Pflaum.(12) This study indicated that heavy and light hydrocarbons, lead, phenols, and aldehydes were the primary contaminants being produced by outboard motors. (It should be pointed out that these are basically the same contaminants mentioned in earlier studies made by English.(7)) Tests were run in the laboratory with the 6, 18, and 40 horsepower motors using oil to gas ratios of 1:25 and 1:50. It was found that emissions were dependent on engine speeds with minimums occurring between zero and half throttle. Engine wear was also found to be significant in increasing the amount of contaminants discharged from the motors. As in the English studies, phenols and lead were found in significant amounts.

Muratori explained the general operating characteristics of the two-cycle engine and pointed out the reason for its inherent polluting capabilities.(17) The basic concept of a pollution control device was mentioned along with the reasons for it being so long in becoming a reality. He stated that with a conservative 10 percent fuel wastage, at least 100 million gallons of unburned fuel were being discharged annually (1968 estimate) into the waters of the United States. This represented a cost of about $50 million.

One of the more recent studies on pollution by outboard motors was conducted by Stillwell and Gladding in October 1969.(28) This study was to determine amounts of unburned fuel discharged and to ascertain whether any changes can be made in the basic construction of the two-cycle engine to reduce or eliminate these discharges. Tests were run on 5, 33, 40, 50 and 60 horsepower motors of different make and model (Johnson, Evinrude,

and Gale). All motors were operated at 1500 RPM ± 100 with standard test propeller in a test tank. The gasoline to oil ratio was 50:1. The fuel waste percentage was 1.57, 31.25, 31.25, 53.1, and 54.7 percent, respectively.

It should be pointed out that one recent report by Environmental Engineering, Inc. of Gainesville, Florida contradicts all previous pollution studies in the outboard motor field. This firm was commissioned by Kiekhaefer Mercury to make a complete survey of Lake X, used extensively by Mercury as a testing ground for outboard engines. According to the report, nearly three million gallons of gasoline and oil have been used there in the past ten years. This lake was compared to a nearby lake which has "almost never" been used by power boats and has no exposure to contamination. Numerous samples were collected from both lakes and analyzed for organic compounds known to be found in exhaust emissions of internal combustion engines. The result was that neither lake contained any of these organic compounds. The conclusion was made that either the organic compounds were readily broken down by bacteria or they are in such minute quantities as to be undetectable.

About forty other chemical tests were performed including analysis for iron, manganese, lead, zinc, copper, sulfate, chloride, silica, phosphate, nitrogen, available oxygen, and oxygen demand. Here again the results indicated no pollution occurring.

Biological studies were also undertaken at both lakes. Bacterial counts were found to be normal and there was no observable effect on plankton or bottom organisms.

SECTION V - EQUIPMENT AND MATERIALS

The following is a listing of principal items of equipment with a brief statement of their purpose:

TEST TANKS

Two Bilnor Corporation swimming tanks were used for the tests. The tanks were both Models No. 307.45582 and were 18 ft in diameter with a 4 ft depth. The tanks were made with a vinyl plastic liner supported by a steel frame.

ENGINE SUPPORT PLATFORM

A wooded walkway with access stairways was built just above the tanks and used to support the engines. The walkway was bolted to the floor and laterally braced against the concrete block wall of the building in which the tests were conducted. Steel engine mounting plates were located above the center of each tank.

OUTBOARD ENGINES

The engines used in this work included a 1½ horsepower Evinrude engine used for screening purposes, a 33 horsepower Evinrude, and a 65 horsepower Mercury engine. Accessory fuel tanks were used to supply the engines.

TEST PROPELLERS

Because of extensive splashing, the standard propellers on the Evinrude and Mercury engines were replaced with test propellers provided by the engine manufacturers. The Evinrude propeller was satisfactory, but the Mercury unit did not perform well and could not be used.

TACHOMETER

A Sea-Speed Tachometer, Model 564-B was used in conjunction with the 33 horsepower Evinrude engine to obtain engine speeds.

WATER COLUMN SAMPLERS (see Fig. 1)

Three samplers were used for obtaining depth samples. They consisted of an aluminum support frame and a 5 ft section of 1½ inch diameter Pyrex glass pipe. The base of the support frame was a 6 inch by 6 inch aluminum plate with a 5/8 inch I.D. copper tube fitted through the center of the plate. A shut-off valve was connected to the tube. Two 6 ft aluminum rods of ½ inch diameter were threaded into the base plate to serve as vertical supports for the glass pipe. Ring clamps attached to the rods provided a guide and support for the glass pipe, which was seated on a No. 9 rubber stopper mounted over the copper tubing outlet device.

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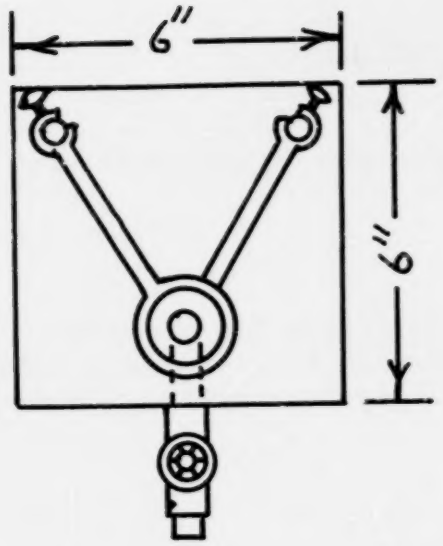
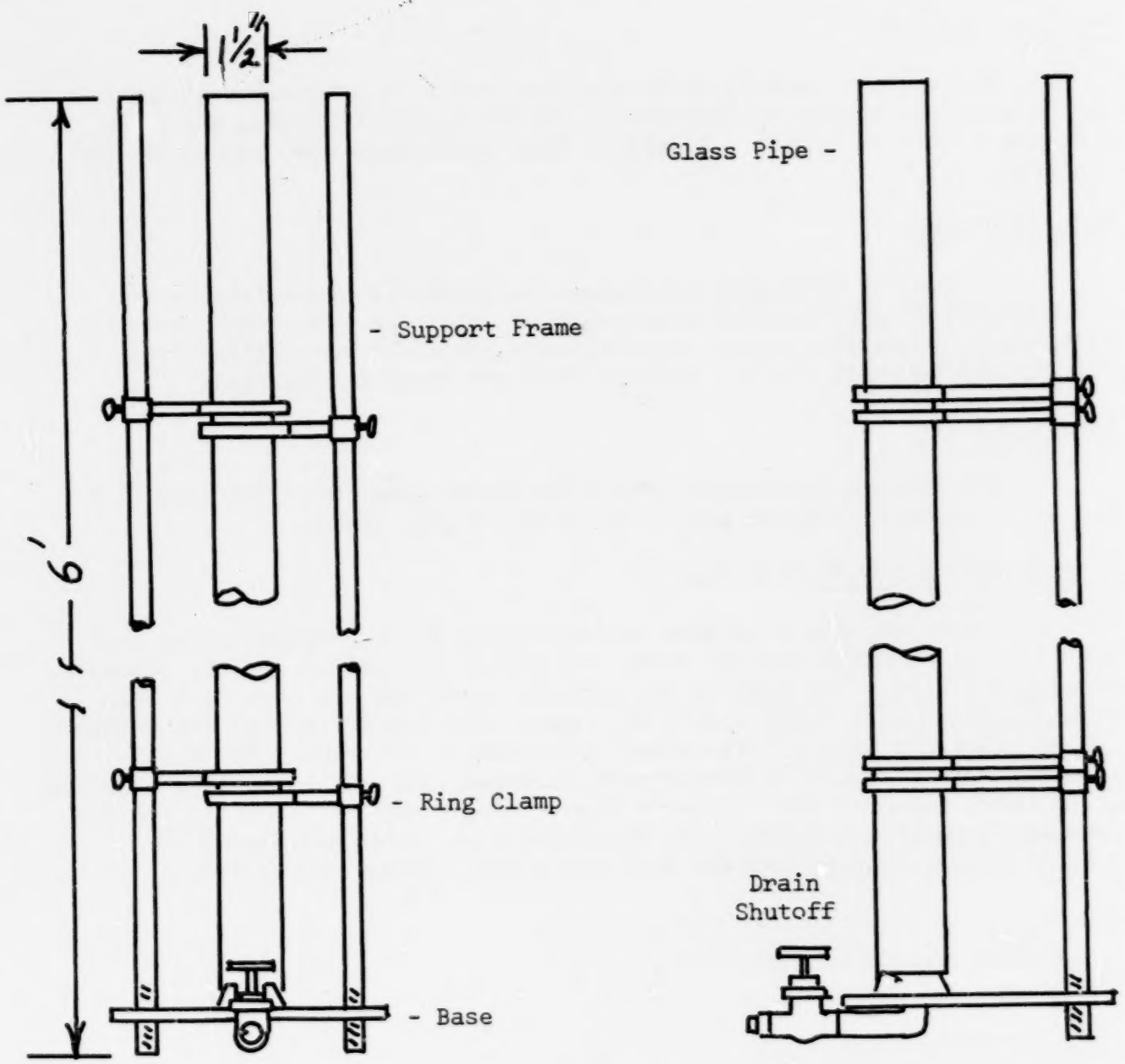


Figure 1
Water Column Sampler



WATER SURFACE SAMPLERS

Samplers consisted of a 12 inch length of 25 mm glass tubing, supplied with No. 6 rubber stoppers.

CARBONACEOUS ANALYZER

The carbon content of samples was determined by a Beckman Carbonaceous Analyzer with a Beckman Model 315 Infrared Analyzer and strip chart recorder.

ESSO OIL ANALYZER

A device developed by Esso Engineering for determining low concentrations of oil in water was borrowed for this work. The instrument depends upon measuring the change in frequency of vibration of a piezoelectric quartz crystal, caused by the weight of oil from a sample extracted with methylene chloride, from which the methylene chloride is evaporated. The instrument was calibrated with known samples.

OIL TEST PAPERS

Concentrations of oil were examined using test papers manufactured by Machery, Nagal and Company, Germany, and distributed by Gallard-Schlesinger Chemical Manufacturing Corporation, Carle Place, New York.

TANK PUMP

A 50 gpm centrifugal pump manufactured by F. E. Myers and Bros. Co., Model 100M-1/3 was used to empty the tanks between runs. Flexible PVC pipe was used for the suction line and polyethylene pipe used for discharge.

PLASTIC GAS CANS

Three gas cans used for mixing and storage of fuel - 1½, 3, and 5 gallon cans from Will Scientific, Inc.

FUEL

Mobil regular gasoline and Formula 50 Quicksilver Motor Oil made by Kiekhaefer Mercury were used. A 50:1 ratio of gasoline to oil was used as specified by the engine manufacturer.

CRANKCASE EXHAUST COLLECTION DEVICE

A plug and by-pass tube device was used to collect the crankcase drain exhaust. It is manufactured by the Goggi Corporation, Staten Island, New York.

WARBURG RESPIROMETER

Used for oxygen-uptake measurements.

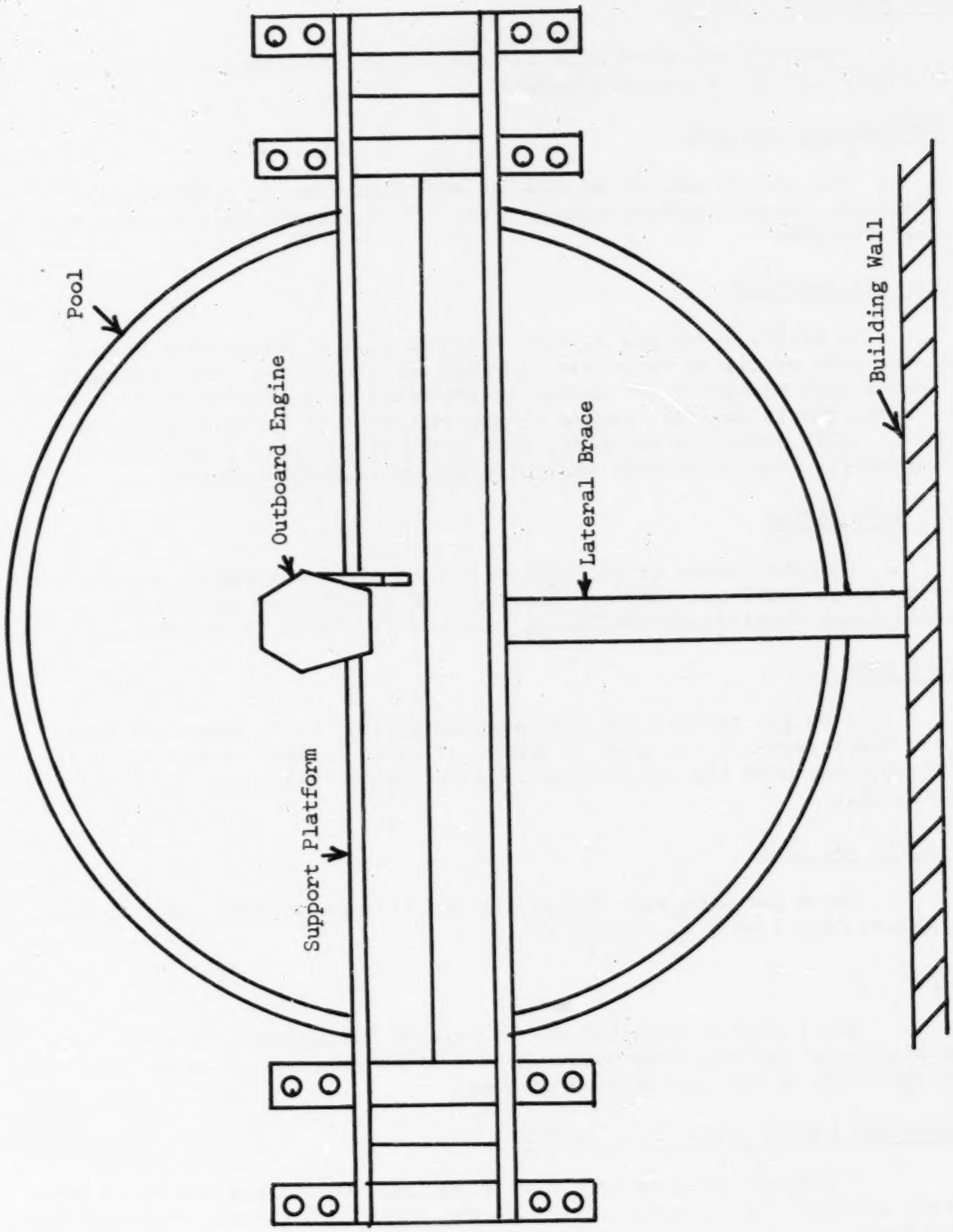


Figure 2

Engine Testing Layout - Plan View

SECTION VI - PROCEDURE

ENGINE TEST RUNS

Test runs were made both with the crankcase exhaust collected by the Goggi device, and with it discharged to the water as it would be under normal operation of the engine. In both cases, the engine was allowed to warm up at idle speed for approximately five minutes and was then run for a half hour at each of three rpm levels. The rpm levels used were usually 1000, 2000, and 3000 rpm. The fuel tank was filled to a pre-set mark on the neck of the tank inlet before the engine was run at each rpm level. At the end of each half hour run, the tank was refilled to the mark and the fuel usage was measured by the amount of fuel needed to refill the tank. In the runs in which the crackcase exhaust was collected, the waste was discharged into a beaker and the volume collected was measured for each rpm level. All tests were made with the engine engaged in forward gear.

SAMPLING PROCEDURE

Samples of water were taken before and after each run at each rpm level. In those cases in which one half hour run was immediately followed by another run, the last sample for the preceding run was used also as the initial sample for the following run. When there was any time lapse between runs, separate before and after samples were taken. Samples were taken from the 14" and 28" depths and from the surface. These depths correspond to approximately the 1/3 and 2/3 depths of the pool since the total pool depth was 43". In the initial runs, all samples were taken with the water column sampler, but it was found that a satisfactory surface sample could not be obtained in this manner. For this reason, the surface sampler was developed and used in all subsequent runs. A sample was also taken from a depth of 1" off the pool bottom in several of the final runs.

Samples taken with the water column sampler were collected by resting the support frame on the pool bottom and then lowering the glass pipe through the water column and snugly seating it on the rubber stopper mounted on the base. With the drain shutoff closed, it was then possible to remove the entire unit from the pool, and samples could be drawn from any level by draining the level in the tube down to the desired level and then drawing a sample into a sample bottle. Samples taken for analysis with the carbonaceous analyzer were immediately refrigerated and analyzed within 24 hours. Methylene chloride was added to those samples which were to be analyzed with the oil analyzer.

PROCEDURE FOR ANALYSES

Carbonaceous Analyzer

The carbonaceous analyzer consists of three sections: a furnace, an infrared analyzer, and a strip chart recorder. A 40 µl sample is injected through a sampling port into a 950°C constant temperature catalytic furnace. The solution is vaporized and the carbonaceous material is oxidized to CO_2 and steam. A stream of pure oxygen carries the CO_2 and steam

mixture to a condenser and the condensates are removed. The CO_2 and the remaining water in the oxygen stream then enter a Beckman Model 315 Infrared Analyzer which measures the amount of CO_2 in the stream and the amount is recorded on a strip chart recorder. The peak height is then measured, and by reference to a calibration curve, a direct reading in terms of milligrams of carbon per liter is obtained.

The procedure used in the analyses for total carbon followed that recommended in the Beckman Carbonaceous Analyzer Instruction Booklet (Bulletin 4059). Samples analyzed for organic carbon were first acidified to a pH of approximately 2.0 and then were bubbled with nitrogen for five minutes. This procedure effectively converts all the carbonates and bicarbonates to CO_2 and removes the CO_2 by purging with the nitrogen gas. Once the inorganic carbon had been removed, the procedure followed was the same as for the total carbon analyses.

Oil Analyzer

Oil measurements were made using an oil analyzer developed by Esso Engineering and Research Company. Samples taken for analysis with this machine were first extracted with an equal volume of methylene chloride. This produced a solution of oil in methylene chloride that was of the same concentration as was the water solution. A microliter syringe was then filled with this solution, and a second syringe was filled with pure methylene chloride. The analyzer contained two piezoelectric quartz crystal resonators. These crystals vibrated at a very specific frequency when subjected to an electrical current, and this frequency changed when a weight was placed on the crystal. A 1 µl sample of the methylene chloride and oil solution was injected onto one crystal and 1 µl of methylene chloride alone was injected on the other. The pure methylene chloride evaporated to dryness, while the methylene chloride and oil solution left an oil residue. The weight of this residue caused the frequency of vibration of the one crystal to change and the difference in frequencies between the two crystals was measured and the result read directly on a meter as ppm of oil. The analyzer had four ranges of sensitivity. Each sample was analyzed four times, and values from all four ranges were recorded. Results were obtained by averaging the values from the two ranges which gave the best agreement. The detailed procedure used was as follows:

1. Wash crystals in methylene chloride
2. Air dry
3. Set range to #1
4. Adjust zero
5. Insert empty syringes until the needle tips just clear the crystals
6. Center the needle over the crystal
7. Readjust zero
8. Fill syringe #1 with sample and syringe #2 with methylene chloride
9. Introduce 1 µl each of the sample and the solvent at the same time and allow to evaporate
10. Read the value obtained for each of the four ranges
11. Repeat the entire procedure four times

Oil Test Paper

The oil test paper was simply placed in contact with the sample and the color change was noted. In the presence of oil, purple discolorations appear. The intensity and size of the purple spots indicate the quantity of oil in the water. When there is no oil in the water, the paper is neither moistened nor discolored.

SECTION VII - RESULTS

Initial fuel wastage tests were run on a 33 horsepower Evinrude engine. Fuel and exhaust products being discharged were collected by means of a plug and by-pass tube device manufactured by the Goggi Corporation. The engine was a 1968 model and had been used under normal boating operation. No attempt was made to tune up or adjust the engine for these first runs. Subsequent runs were made with the engine after tune-up. The engine tune-up consisted of replacing the spark plugs and setting the carburetor adjustments to factory specifications. The results of these tests are tabulated in Tables 1 and 2.

Table 1

Fuel Wastage - Untuned Engine

Engine Speed rpm	Duration min	Fuel Used ml	Fuel Wasted ml	Percent Wasted
1,000	30	2,229	680	30.51
2,000	30	3,445	245	7.11
2,500	30	4,965	370	7.45

Table 2

Fuel Wastage - Engine Tuned

Engine Speed rpm	Duration min	Fuel Used ml	Fuel Wasted ml	Percent Wasted
1,000	30	1,976	515	26.06
2,000	30	3,000	180	6.00
3,000	30	4,215	125	2.97

A summary of all operating and analytical data is given in Table 3. During the first several runs, all samples were taken using the water column sampler. Samples were taken at points #1, #2, and #3 as shown in Figure 3. This procedure was found to be satisfactory for points #1 and #2, but it was not possible to get a satisfactory surface sample (point #3). There were two reasons why the surface samples obtained with this procedure were not considered reliable. First, much of the surface film adhered to the glass pipe as water was withdrawn from the sample. Secondly, the design of the outlet device was such that there was always a small amount of water remaining in the tube after the sample was taken. These two factors made it impossible to obtain a reliable surface sample with the water column sampler. To avoid these problems, it was decided to use the surface sampler to sample the top layer rather than use point #3 from the water column sampler. The surface sampler was used for all samples after sample number 8.

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Table 3

Summary of Data

Sample	RPM	Fuel Used ml	Fuel Wasted ml	% Wasted	Total Carbon mgC/l pt. 0	Total Carbon mgC/l pt. 1	Total Carbon mgC/l pt. 2	Organic Carbon mgC/l pt. 0	Organic Carbon mgC/l pt. 1	Organic Carbon mgC/l pt. 2	Esso Analyzer ppm pt. 1	Esso Analyzer ppm pt. 2	Esso Analyzer ppm pt. 3
1	clean pool	-	-	-	-	-	-	-	-	-	5.62	0.	19.75
2	½ hr warmup	-	-	-	-	-	-	-	-	-	10.80	0.	0.
3	2000	3445	245	7.1	-	-	-	-	-	-	33.00	0.	15.00
4	4 days later water sample	-	-	-	-	-	-	-	-	-	0.	14.13	25.50
5	warm-up	-	-	-	-	-	-	-	-	-	18.50	22.80	16.87
6	1000	2229	680	30.5	-	-	-	-	-	-	23.66	57.50	55.00
7	1 day later water sample	-	-	-	-	-	-	-	-	-	18.00	9.25	19.00
8	2500	4965	370	7.9	-	-	-	-	-	-	12.00	5.38	0.

CLEANED POOL AFTER SAMPLE NO. 8

Table 3 (continued)

Summary of Data

Sample	RPM	Fuel Used ml	Fuel Wasted ml	% Wasted	Total Carbon mgC/l pt. 0	Total Carbon mgC/l pt. 1	Total Carbon mgC/l pt. 2	Organic Carbon mgC/l pt. 0	Organic Carbon mgC/l pt. 1	Organic Carbon mgC/l pt. 2	Esso Analyzer ppm pt. 0	Esso Analyzer ppm pt. 1	Esso Analyzer ppm pt. 2	Top 1"
9	warm-up	-	-	-	-	10.0	10.3	-	4.0	4.0	-	0.	2.5	354.2
10	1000	1976	515	26.	-	11.0	10.5	-	4.5	3.0	-	7.0	0.	119.0
11	2000	3000	180	6.	-	13.8	13.0	-	3.6	4.0	-	8.25	11.2	130.26
12	3000	4215	125	2.97	-	17.5	17.0	-	4.0	4.5	-	4.0	17.0	166.24
13	5 days later water sample	-	-	-	-	13.5	13.5	-	6.5	4.75	-	0.	0.	-
14	warm-up	-	-	-	-	15.0	16.25	-	7.0	4.75	-	29.0	0.	138.24
15	1000	2000	-	-	-	20.5	20.5	-	4.75	4.50	-	0.	0.	181.5

CLEANED POOL AFTER SAMPLE NO. 15

Table 3 (continued)

Summary of Data

Sample	RPM	Fuel Used ml	Fuel Wasted ml	% Wasted	Total Carbon mgC/l pt. 0	Total Carbon mgC/l pt. 1	Total Carbon mgC/l pt. 2	Organic Carbon mgC/l pt. 0	Organic Carbon mgC/l pt. 1	Organic Carbon mgC/l pt. 2	Esso Analyzer ppm pt. 0	Esso Analyzer ppm pt. 1	Esso Analyzer ppm pt. 2	Top 1"
16	clean pool	-	-	-	-	15.75	10.0	-	-	4.50	-	6.13	0.	155.0
17	warm-up	-	-	-	-	10.5	10.0	-	3.6	3.8	-	-	-	-
18	3000	4645	-	-	-	18.5	25.0	-	4.5	3.5	-	0.	0.	168.75
19	2000	3000	-	-	-	29.5	26.0	-	3.6	3.6	-	5.16	5.75	182.62
20	1000	2000	-	-	-	31.0	31.5	-	3.6	4.0	-	10.62	12.0	163.12
20A	4 days later	-	-	-	-	-	-	-	-	-	-	-	-	580.0

CLEANED POOL AFTER SAMPLE NO. 20A

Table 3 (continued)

Summary of Data

Sample	RPM	Fuel Used ml	Fuel Wasted ml	% Wasted	Total Carbon mgC/l pt. 0	Total Carbon mgC/l pt. 1	Total Carbon mgC/l pt. 2	Organic Carbon mgC/l pt. 0	Organic Carbon mgC/l pt. 1	Organic Carbon mgC/l pt. 2	Esso Analyzer ppm pt. 0	Esso Analyzer ppm pt. 1	Esso Analyzer ppm pt. 2	Top 1"
21	warm-up	-	-	-	11.0	10.0	9.8	5.5	2.5	2.3	-	0.	5.87	77.5
22	1000	1850	-	-	15.0	12.6	12.6	5.5	3.0	2.7	13.13	14.5	13.0	58.6
23	2000	3000	-	-	16.5	16.3	19.0	3.8	3.0	3.6	11.50	0.	5.66	57.87
24	3000	not known	-	-	22.8	25.5	32.0	3.8	4.0	4.5	16.75	5.75	3.0	997.6
25	2 days later	-	-	-	25.0	28.5	30.0	4.0	3.5	3.6	14.12	15.67	10.38	502.5
26	4 days later	-	-	-	20.7	27.5	22.7	7.2	5.0	4.2	3.0	12.0	6.5	787.5
27	6 days later	-	-	-	21.7	27.5	23.5	6.3	5.9	4.2	4.5	4.88	6.38	180.0

Table 3 (continued)

Summary of Data

Sample	Location	RPM	Fuel Used ml	Total Carbon mgC/l pt. 0	Total Carbon mgC/l pt. 1	Total Carbon mgC/l pt. 2	Inorganic Carbon mgC/l pt. 0	Inorganic Carbon mgC/l pt. 1	Inorganic Carbon mgC/l pt. 2	Esso Analyzer ppm pt. 0	Esso Analyzer ppm pt. 1	Esso Analyzer ppm pt. 2	Top 1"
28	#1	clean pool	-	12.	13.	10.	5.5	5.5	3.5	0.	0.	0.	96.0
28	#2	clean pool	-	11.	11.	10.	4.0	3.5	3.5	0.	0.	0.	96.75
28	Avg	clean pool	-							0.	0.	0.	96.38
29	#1	warm-up	-	9.	10.	9.	3.5	3.0	4.5	*	*	*	49.75
29	#2	warm-up	-	9.	10.	9.	3.0	3.0	3.5	*	*	*	91.2
29	Avg	warm-up	-							*	*	*	70.47
30	#1	warm-up	-	10.	10.	9.	2.5	3.0	3.0	1.0	0.	0.	81.87
30	#2	warm-up	-	10.	10.	9.	2.5	3.5	3.5	0.	0.	0.5	233.24
30	Avg	warm-up	-							0.5	0.	0.25	157.55
31	#1	1000	2020	10.	13.	10.	3.0	3.0	3.0	0.	0.	2.0	111.12
31	#2	1000	2020	11.	10.	10.	2.8	3.5	3.0	4.0	0.	1.0	212.37
31	Avg	1000	2020							2.0	0.	1.5	161.74
32	#1	2000	4150	10.	21.	13.	4.0	5.0	4.5	0.	1.75	0.	106.12
32	#2	2000	4150	10.	12.	20.	4.0	3.5	5.0	0.	0.	3.25	151.5
32	Avg	2000	4150							0.	.875	1.675	128.81
33	#1	3000	5290	13.	13.	16.	6.0	7.0	7.0	0.	0.	.25	112.5
33	#2	3000	5290	13.	30.	14.	5.5	7.5	5.5	2.75	1.0	1.25	150.75
33	Avg	3000	5290							1.375	0.5	0.75	131.62

*Analyses not run. Bottles used had plastic liner in top which dissolved in methylene chloride.

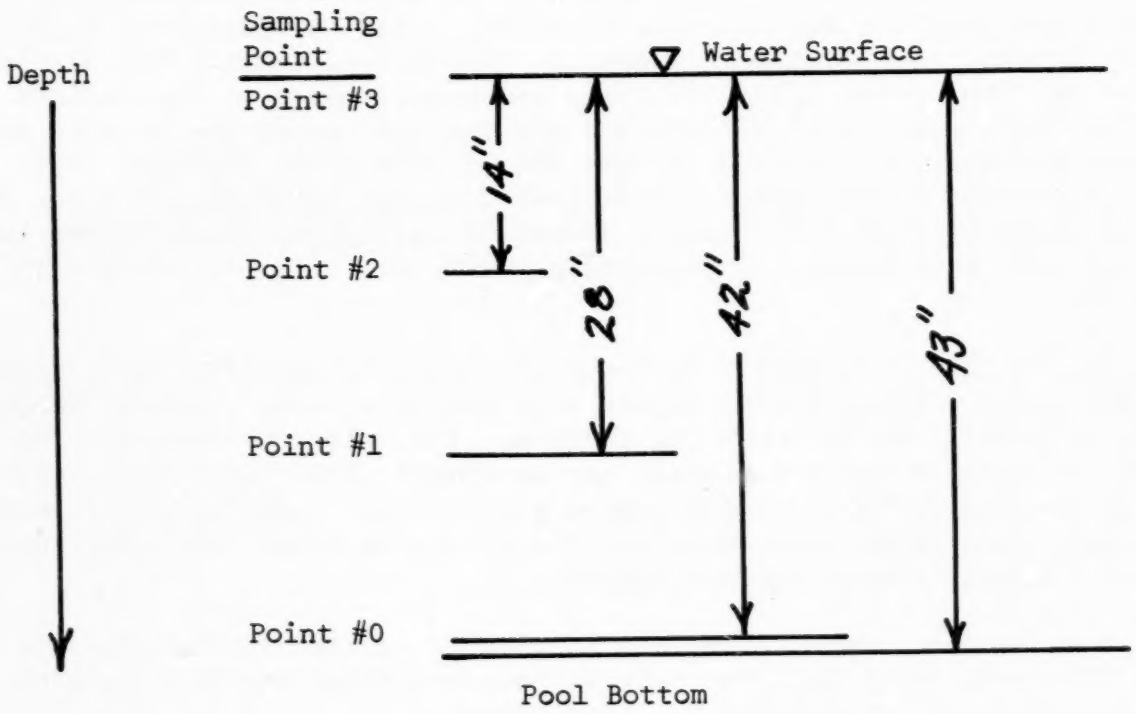

Figure 3

Depth of Sampling Points

Results obtained with the Esso Analyzer for the first eight samples were erratic and indicated that a second method of analysis should be employed as a check. For this reason, carbon analyses were run on all subsequent samples except surface samples. Carbon analyses were not run on the surface samples because it was not felt that oil on the surface could be adequately dispersed throughout a water sample for use with the carbon analyzer.

The last seven samples taken (Samples 21 through 27) included samples from 1" above the pool bottom. It was felt that these samples would give additional information regarding the distribution of oil in the water.

Use of the oil test papers was initiated with sample number 16. At first, they were used as directed by the manufacturer (samples 16 through 20). The procedure used was simply to wipe the papers along the water surface several times. In the absence of oil no color change in the paper was observed. When oil was present, purple discolorations occurred. Following sample number 20, it was discovered that the oil test papers could be used to demonstrate qualitatively the distribution of oil in the top two inches or so of water. This had to be done carefully. If the test paper was simply lowered lengthwise into the water, it became spotted along its entire length. However, if the test paper was lowered inside an inverted test tube, excellent visible results were obtained. The test paper was held inside the inverted test tube and lowered to the desired depth. The air in the test tube kept the water from contacting the paper. Once at the desired depth, the test tube was slowly removed and the test paper was held in place for approximately five minutes. At the end of this time, the test paper was quickly pulled out of the water. This procedure was performed on three occasions, at forty minutes after sample number 20 was taken, twenty-three hours after, and four days later. A decreasing color intensity was noted with increased time.

It was then felt that this technique could be used for other depths within the pool. Four oil test papers were placed at four depths. These were 0", 14", 28", and 43" from the surface. The motor was then run for one half hour at each of three different engine speeds (1000; 2000; and 3000 rpm). At the end of this run the papers were quickly removed. Surface wipe samples were also taken after each individual engine speed run. The papers indicated oil only in the surface layers.

The oil test papers were most helpful in indicating the presence of various oil concentrations. The papers, however, faded rapidly and consequently could not be reproduced for this report.

Biodegradability studies of the exhaust products from the operation of outboard engines and also of the initial fuel were made. Preliminary results indicate that motor oil (50:1 two cycle), as well as exhaust products, are able to support microbial growth. The initial rates of growth of cultures utilizing non-volatile exhaust products (volatile removed by heating to 90°C) as sole nutrients were the same as the initial growth rates on these exhaust products supplemented with 10 percent nitrogen as

$(NH_4)_2PO_4$, 10 percent nitrogen plus growth factors, or water from Lake George. Table 4 shows the data from a typical study of this type.

To determine the effect of increased oxygen transfer rate on the conversion of carbon to cell mass, tests with various shaker volumes and speeds were made. The results shown in Tables 5 and 6 show that increased transfer capability resulted with decreased shaker volume and increased shaker speed.

Preliminary studies were also made with a Warburg respirometer apparatus which supported the above results.

Table 4

Growth of Ps. fluorescens on Fuel Wasted by Engine Operating at 2000 rpm (1600 ppm)

Nutrient Conditions	Time (hours)	Cells/l
Fuel	2	$\sim 10^7$
	4	4.8×10^9
	6	7.0×10^{10}
	10	8.3×10^{14}
	25	$\sim 10^{15}$
Fuel + 10% N	2	5.8×10^7
	4	9.1×10^9
	6	5.3×10^{10}
	10	1.9×10^{14}
	25	3.4×10^{15}
Fuel + 10% N + 1% yeast extract	2	$\sim 10^7$
	4	2.8×10^{10}
	6	1.0×10^{13}
	10	2.4×10^{16}
	25	3.0×10^{17}
1% yeast extract	2	---
	4	---
	6	0.9×10^5
	10	---
	25	1.2×10^5
Fuel + filtered Lake George water	2	$\sim 10^7$
	4	1.4×10^{10}
	6	1.5×10^{11}
	10	2.5×10^{14}
	25	4.2×10^{15}

Table 5

Effect of Shaker Speed and Volume on
Oxygen Transfer Capacity (Sulfite Value)

Speed	Volume	Sulfite Value (mmoles O_2/l/min)
low	100 ml	0.46
	50 ml	0.61
high	100 ml	1.00
	50 ml	1.15

Table 6

Effect of Increased Aeration on Cell Growth
(*Ps. fluorescens*)

Conditions	Time (hours)	Cells/l
0% N low speed	4	4.8×10^{9}
	6	7.1×10^{10}
	10	8.3×10^{14}
10% N low speed	4	1.5×10^{10}
	6	1.4×10^{10}
	10	3.8×10^{14}
0% N high speed	4	1.1×10^{10}
	6	1.6×10^{11}
	10	1.6×10^{15}
10% N high speed	4	2.9×10^{10}
	6	2.6×10^{11}
	10	1.0×10^{15}

SECTION VIII - DISCUSSION

A number of screening tests were made with a 1½ horsepower Evinrude motor for the purpose of ascertaining desirable water depths in the tanks, the amount of splashing to be expected, the nature of the exhaust discharges, and other pertinent information. It became apparent that a considerable amount of splashing was to be expected and subsequent tests were made with test propellers substituted for standard models. This allowed operation at any desired speed without injury to the motors. The 33 horsepower Evinrude was particularly satisfactory in this regard. Problems were encountered with the 65 horsepower Mercury which splashed excessively. The test propeller sent with this engine was not satisfactory and did not perform well. Consequently, the data with this motor was not considered to be meaningful.

The tests made to measure the quantity of fuel wastage indicate that an increase in engine speed decreases the amount of exhaust products. They also point up the importance of engine tuning. These results agree closely with the results of others for similar engines.(23,26)

From the data shown in Table 3 it will be noted that total carbon results show a consistent increase with engine operation. On the other hand, organic carbon results, while fluctuating somewhat, remained essentially unchanged during engine operation. This suggests that the increasing values of total carbon were due to entrainment of carbon dioxide by turbulent mixing of the water by the engine propeller. This hypothesis is supported by the fact that the relative increase of total carbon was greater at higher values of engine rpm. This seems to be independent of the order in which a series of rpm runs is performed. It should be pointed out that the level of total carbon six days after a 1000, 2000, 3000 rpm series run had not dropped to the original value and, indeed, seemed to level off at this point. This is due to the fact that saturation values for carbon dioxide in water were well above concentrations produced during engine runs. The fact that inorganic carbon concentrations in water seemed to increase as a result of the operation of outboard motors could be significant in the overall pollution contribution made by these engines. This is an area for possible future concern but it is not directly related to this study.

Results with the Esso Analyzer on samples taken below the surface were rather erratic and did not seem to follow any consistent trend that could be compared to engine operation. It is believed that this behavior is due in part to the nature of the analyzer. The instrument required a considerable degree of technique for its successful operation and was subject to error unless precautions were constantly observed. Since reproducibility was difficult to achieve in many instances, particularly for values less than about 50 ppm, it is believed that heavy reliance should not be placed on absolute values from the Esso Analyzer. The trends, however, appear to be significant and support other evidence that indicates that past products separated quite completely and accumulated on the water surface.

An attempt was made to correlate the accumulation of oil in the surface layer (assumed to be 1") with calculated values based on the results of the previous fuel wastage studies. The method of calculation is

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included along with the calculated values (Table 7). A comparison of calculated cumulative oil concentrations and actual oil concentrations in the surface layer is presented in Table 8. While obvious discrepancies occur, some interesting observations may be made. At the end of run 2, which was run in descending order of engine rpm, the actual concentration was well below the calculated concentrations. However, four days later the actual concentration had risen to over one-half of the calculated value. At the end of run 3, which was run in ascending order of engine rpm, the actual concentration was very close to the calculated concentration. This eventually dropped off after six days to one similar to those obtained from the surface of a "clean pool". These comparisons bear out hypothesis that most of the waste oil discharged into the water accumulates in the surface layer (at least the top one inch) and reinforces other results obtained in the study.

The oil test papers were useful in determining, qualitatively, relative amounts of oil present. At first they were employed for surface wipes and they seemed to give sound basis for comparison from one point in time to another. But, by far, their most important use in this study was in determining the distribution of oil with depth. This distribution could be found at any one point in time or the test papers could be left in the water at the desired depth for any length of time, thus giving the cumulative effect of the oil movement (if any) during that time. As previously mentioned, these papers were placed at various depths within the pool during a 1000, 2000, 3000 rpm series run to obtain the cumulative effect of waste discharge. Although the papers below the surface show a slight presence of oil, the paper placed at the surface clearly indicates that most of the oil accumulated there. A number of tests show this situation remains relatively unchanged for at least four days afterward.

In the biodegradability studies measurements of microbial activity were made by assessing the numbers of viable cells as a function of time. Other common methods such as turbidity are precluded due to the emulsion that results in the oil-water system and the adherence of the microbial cells to the oil droplets. Insufficient cell mass was obtained in these studies for reliable dry weight or protein estimation. Pure cultures of Pseudomonas fluorescens and Pseudomonas oleovorans, as well as controlled mixed cultures of Ps. fluorescens and Ps. oleovorans, and random mixed cultures are employed. Ps. fluorescens is a common soil and water organism which is known to oxidize a wide range of compounds. Ps. oleovorans has been isolated from oils used in cutting compounds.(13)

The data shown in Table 4 show that the exhaust products alone contained adequate accessory nutrients to support the degree of microbial growth observed under these conditions. The degree of growth, however, was not as much as expected if complete utilization of these products occurred. Stepwise growth on spent fuel (including volatile) was observed. Growth on fresh motor oil was less, suggesting the presence of gasoline residues or partial degradation products in the spent fuel, yielding a more biodegradable product.

Table 7

Calculated Oil Concentrations in Top 1"

RPM	Fuel Wasted ml	Calculated ppm in Top 1"
1000	680	793
1000	515	600
2000	245	286
2000	180	210
2500	370	432
3000	125	146

Sample Calculation

RPM = 1000 Fuel Wasted = 680

Density of waste fuel = 0.7 gm/ml

$$\text{mg/l waste in top 1"} = \frac{680 \times 0.7 \times 1000}{\pi \times (18/2)^2 \times (1/12) \times 28.32} = 793 \text{ mg/l}$$

Table 8

Cumulative Oil Concentration in Top 1" of Water

Run	RPM	Calculated ppm	Actual ppm
1	1000	600	181.50
2	3000	146	168.75
	2000	356	182.62
	1000	956	163.12
	4 days later	956	580.00
3	1000	600	58.60
	2000	810	57.87
	3000	956	997.60
	2 days later	956	502.50
	4 days later	956	787.50
	6 days later	956	180.00

Growth under the conditions of all of these experiments is only about 1 percent of that anticipated considering the chemical nature of the fuel. Greater than 90 percent conversion of highly reduced carbon compounds to cells can be expected under the proper oxidative conditions. Therefore, the effect of increasing the oxygen transfer capability of the growth system was investigated.

A sulfite value determination(2) showed that the oxygen transfer capability of the shaker was increased both by reducing the volume of liquid in the shake flask and by operating the shaker at a greater number of reciprocations per minute as shown in Table 5.

Consequently, duplicate flasks were prepared and the cell yield determined in flasks containing 100 ml of medium at low and at high speed. The nutrient conditions for the experiment reported in Table 6 are 1600 mg C/l of waste fuel from an engine operating at 2000 rpm and 0 percent or 10 percent N as $(NH_4)_3PO_4$.

These results indicate that approximately a two-fold increase in cell number is achieved by operating at high speed. The oxygen transfer capacity at high speed is about twice that of low speed. According to these results, oxygen seems to be the limiting factor under these conditions of growth. Increasing levels of oxygen transfer capacity are being studied currently to determine the degree of fuel utilization possible by microbial activity when oxygen is not limiting. These current studies include a kinetic investigation of the pattern of degradation of the various components of fuel and exhaust products from outboard engines by both pure and mixed cultures.

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16. Abstract

A reconnaissance study has been made to determine the extent of pollution which results from the operation of a two-cycle outboard engine. Comparisons have been made of engine operation with and without a pollution control device attached. Studies have also been made of the biodegradability of the fuel and exhaust products.

Tests made in a swimming tank with an untuned engine have shown that the quantity of fuel wasted as exhaust varied from about 7 percent of the volume of fuel used at high speeds, to over 30 percent at low speeds. For a recently tuned engine, the quantity of fuel discharged ranged from about 3 percent at high speeds to about 26 percent at low speeds. When the Goggi pollution control device was installed, these quantities were intercepted and collected rather than discharged with the exhaust.

Analysis at various depths indicated that nearly all products separated from the water in a short time and collected on the surface. Very little dissolved or emulsified oil was noted. Various analytical techniques were studied.

It appears that both fuel and exhaust products are capable of supporting microbial growth. Growth rates, however, appear to be limited by available oxygen.

17a. Descriptors

*Recreation wastes, *Boating, *Water pollution sources, Pollutant identification, Water quality, Analytical techniques, Water pollution control

17b. Identifiers

*Watercraft pollution, *Outboard engine exhaust, Two-cycle engines, Biodegradability of exhaust products.

17c. COWRR Field & Group: 05B

18. Availability

19. Security Class. (Report)

20. Security Class. (Page)

21. No. of Pages

22. Price

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